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Edge of Things: The Big Picture on the Integration of Edge, IoT and the Cloud in a Distributed Computing Environment

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ABSTRACT A centralized infrastructure system carries out existing data analytics and decision-making processes from our current highly virtualized platform of wireless networks and the Internet of Things (IoT) applications. There is a high possibility that these existing methods will encounter more challenges and issues in relation to network dynamics, resulting in a high overhead in the network response time, leading to latency and traffic. In order to avoid these problems in the network and achieve an optimum level of resource utilization, a new paradigm called edge computing (EC) is proposed to pave the way for the evolution of new age applications and services. With the integration of EC, the processing capabilities are pushed to the edge of network devices such as smart phones, sensor nodes, wearables, and on-board units, where data analytics and knowledge generation are performed which removes the necessity for a centralized system. Many IoT applications, such as smart cities, the smart grid, smart traffic lights, and smart vehicles, are rapidly upgrading their applications with EC, significantly improving response time as well as conserving network resources. Irrespective of the fact that EC shifts the workload from a centralized cloud to the edge, the analogy between EC and the cloud pertaining to factors such as resource management and computation optimization are still open to research studies. Hence, this paper aims to validate the efficiency and resourcefulness of EC. We extensively survey the edge systems and present a comparative study of cloud computing systems. After analyzing the different network properties in the system, the results show that EC systems perform better than cloud computing systems. Finally, the research challenges in implementing an EC system and future research directions are discussed.

INDEX TERMS IoT, cloud computing, edge computing, fog computing, multi-cloud.

I. INTRODUCTION

Edge computing (EC) is the new paradigm for a myriad of mission-critical applications.EC has carved a niche in the technological world due to its tremendous performing capabilities of providing real-time data analysis, low operational cost, high scalability, reduced latency and improved quality of service (QoS). Owing to its phenomenal processing abilities, EC will revolutionize various domains such as healthcare, education, transportation, e-commerce and social networks. According to the survey results from Gartner Inc., it is predicted that there will be more than 20 billion networked or connected IoT devices by 2020 [1]. Additionally, McKinsey Global Institute has estimated that the total economic impact ofIoT and EC devices will reach \$11 trillion by 2025 [2]. In recent years, on-demand services with EChavehit the market with giants like Amazon (Echo Dot) [3], Google (Nest) [4], Apple (Smart watch) [5], Cisco (IoxDevnet) [6], GE (Predix) [7], Itron (Open Way Riva) [8] and many more, all vying to be the next big computing revolution in the forefront of technology innovation.

EC follows a decentralized architecture with data processing at the edge of the frontier network nodes to make autonomous decisions. Therefore, the applications running on EC will perform actions locally before connecting to the cloud, thus reducing network overhead issues as well as the security and privacy issues. Furthermore, ECcan easily be integrated with other wireless networks like mobile ad-hoc networks (MANETs), vehicular ad-hoc networks (VANETs), intelligent transport systems (ITSs) and the Internet of Things (IoT) to mitigate network-related and computational problems. When integrated with EC, these network applications make decisions very quickly, avoiding any delay involved in life saving events.

For example, in the healthcare domain, ambulance services enabled with EC are inbuilt with predictive algorithms that can make decisions autonomously without relying on the cloud. In relation to transportation applications, end devices such as smartphones and on-board units when upgraded with EC can quickly predict time-critical events and make decisions that can avoid accidents and traffic congestion, as shown in Figure 1. In e-commerce and social networking domains, EC can potentially enhance the user experience by providing a personalized recommendation system, easy navigation and advanced interactive browsing.

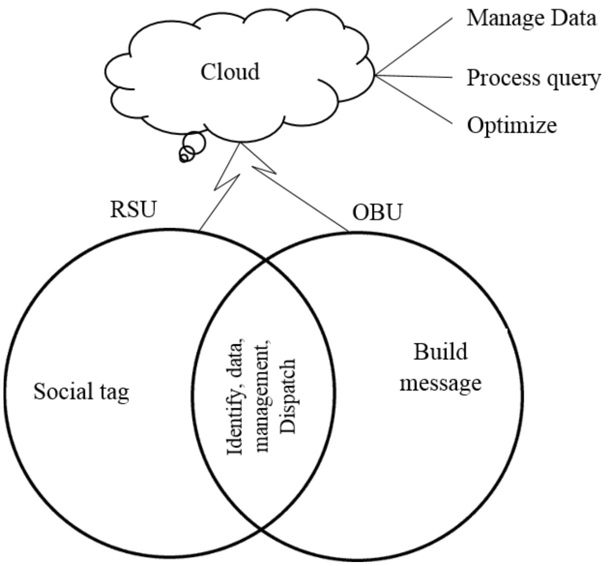

FIGURE 1. EC in VANETs.

The need for the phenomenal computing resource for processing and storing has integrated the vehicular ad hoc networks (VANETs) to cloud. The promising features of novel upcoming edge paradigms were able to deliver an efficient aggregation of sensor information, filter and process with less latency/jitter and high availability/scalability features paved way for the integration of VANETs with edge. This paper, emphasizes that the remedy for cloud computing paradigm is the upcoming edge paradigm.

Even though EC has significantly more advantages when compared with cloud services, it cannot completely replace the cloud. As the analytical model is pushed to the edge of the network to take quick action, some applications still require support from the cloud or a centralized server, resulting in a globalized aggregated result. Futhermore, ECfacesseveral minor challenges in managing network configurations, integrating different wireless networks and IoT applications. These include improper resource management and inaccurate reconfiguration which requires intervention to suitably structure and methodize the system. The scalability property of EC should be redesigned so that it can accommodateand increase the overall processing load. In order to address these challenges, a reliable EC service should be designed dynamically to cope with the network requirements and its applications.

Currently, conventional approaches to EC services seldom focus on scalability, robustness, efficiency, manageability and dynamicity in their applications. The existing literature surveys on EConly focus on the computation and architecture of the technique; they do not analyze the performance of EC. A survey on software-defined networking in collaboration with EC and its application isdiscussed in [9]. An overview of mobile edge networks and its computing and communication capabilities is given in [10]. There are other surveys which discuss the architecture of EC in [11]–[13]; however, they address only the standardization and challenges in EC and no survey specifically addresses the performance of EC with other services like cloud or centralized data centers.

With this motivation, the first section of our research addresses the challenges facing ECover different network applications and then performance analysis is conductedto demonstrate the efficiency of edge systems. We extensively study the existing EC services and classify them based on their network applications. Various scenarios are devised for different network applications like MANETs, VANETs and the IoT and the results are compared with cloud computing services. The research goes a step further and identifiesthe dynamic properties of EC with various network applications and future research directions are also highlighted.

The paper is organized as follows. Section 2 presents an extended survey of EC with different network applications. Section 3 discusses the existing literature on this area of research. Section 4 discusses the integration of the IoT with edges.Section 5 overviews the paper. Section 6highlights the issues and future research directions. Finally, we conclude the paper in Section 7.

II. OVERVIEW OF EDGE COMPUTING

With innovative advancements in information and telecommunications technology, the IoT has evolved to a remarkable degree over the last two decades. The rising demands of users as well as the high data rate generated by the IoT nodes have soared to trillions of gigabytes. This could potentially cause high latency issues and heavy bandwidth utilization. As traditional cloud servers cannot handle this huge amount of data with their centralized network architectures, there is a demand for a more optimized computation management technology in relation to real-time IoT applications. Thus, the need for ECis inevitable as itare designed to remove the barriers of a centralized architecture, pushing computing capabilities to the edge of the network. Though EC is viewed as a promising technology, the research on EC is still in its infancy. In order to design an efficient EC system architecture, the performance of EC and its limitations need be considered Hence, we highlight some of the potential challenges facing EC and elucidate solutions to overcome these challenges.

A. CHALLENGES FACING EC

This section discusses some of the primary challenges that need to be consideredwhen designing an EC architecture.

- The selection of an EC device is critical in different network scenarios. For example, in VANETs, the EC device can be a vehicle or a dedicated edge server. If the vehicles are selected as edge devices, the computation gets distributed but the implementation cost will be high. On the other hand, if the network has a dedicated edge server, it may face challenges in handling the growing demands of the end devices. Thus, to have an effective EC system, the application should incorporate an effective resource management scheme that should be proficient enough to manage both the edge servers and the connecting devices.
- Computation offloading among edge devices is yet another challenging parameter. In a dynamic network, the computations across several edge nodes need to be offloaded in a distributed manner. Without a distributed scheme, the workload becomes biased which eventually increases the load in some systems and drains their battery. Careful policy making combined with effective computation orchestration and management is required to have an energy efficient workload distribution system.
- Automated task allocation between the cloud and the edge is challenging. Due to certain technological constraints in the computation and storage aspect, EC does not entirely exclude cloud computing services, as some computations are still carried out in cloud servers to increase system reliability. A reliable task scheduling scheme needs to be incorporated in the EC which should appropriately allocate tasks to the edge and cloud servers without affecting system performance.
- Reducing communication overhead to achieve QoS in EC is challenging. Without any network standardization and protocols, EC systems may suffer from network related problems, like network traffic congestion and denial of service. An efficient network protocol and standards need to be designed for EC systems to ensure smooth operation without any network lag.
- Mobility management in EC is challenging. The devices utilized in high mobility networks like MANETs and VANETs will face frequent communication disconnection. As a result, data processing and decision making could be significantly affected and delayed. A reliable cooperation scheme should be incorporated in EC devices to effectively handle such mobility issues.
- Ensuring security and privacy in an EC system is also quite challenging. With computations pushed to the edge of the network, information becomes vulnerable to various security threats and attacks. Efficient pseudonym schemes and trust management systems need to be incorporated in the system to handle security issues and thwart possible malicious intrusions/attacks.

As a result, when designing an EC system for a network, researchers and vendor practitioners should consider these aforementioned challenges to achieve the enduring scalability and robustness of the system. As the requirements and challenges are different for every network, such as MANETs, VANETs and the IoT, the design of EC needs to be tailored to individual requirements. We analyse EC services and highlighted some of the important topographies that need to be considered while designing/implementing a new edge architecture.as shown in Figure 2.

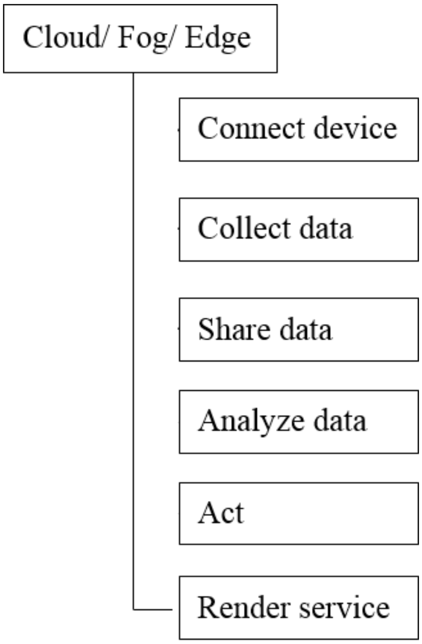

FIGURE 2. **EC topographies.**

There are many papers that discuss the issues and challenges in EC [31]–[33], but there is no research which analyzes the performance of EC with respect to the highlighted challenges. With this motivation, we first present a literature survey on EC in different networks. Based on our literature survey, the performance of the EC is analyzedin relation to the different challenges encountered. Specifically, the selection of appropriate ECdevices and optimized computation workload distribution is benchmarked as a measure by which to analyze the efficiency of the edge system. Different scenarios are devised and the performance of EC is compared and analyzed with cloud computing systems. Based on the outcomes, the efficiency of ECis highlighted and the challenges pertaining to different network systems are addressed.

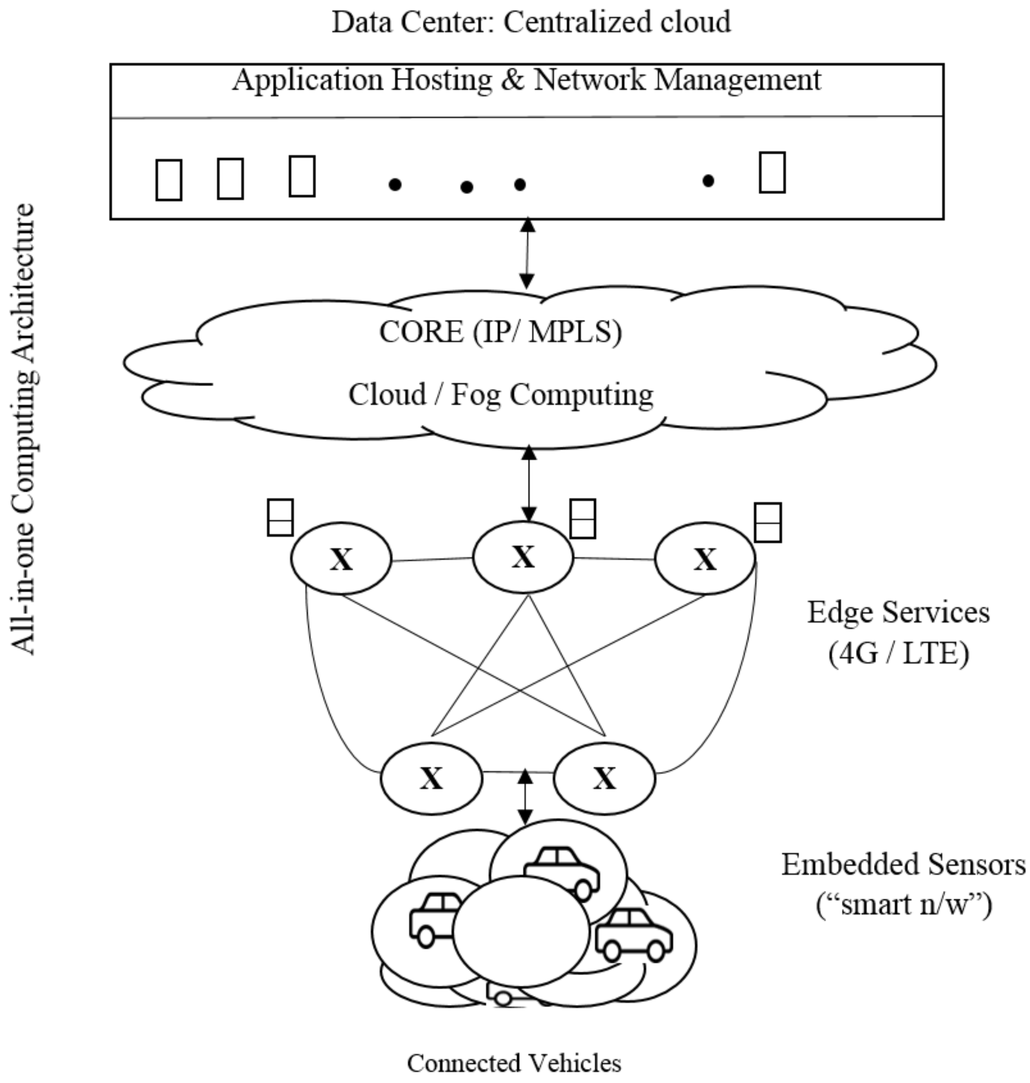

FIGURE 3. All-in-one computing architecture.

III. AN OVERVIEW OF COMPUTING ARCHITECTURE

In this section, we discuss the functional capabilities of different computing architectures with their physical properties and operational methodologies. In the opening sections, EC architecture is discussed, as shown in Figure 3, highlighting its advantages. Further, we compare other computing architectures, such as fog computing (FC), cloud computing (CC) and multi-cloud computing (MCC) and their respective limitations are discussed. In EC architecture, computing/processing servers are installed at the edge of the network within the range of the radio access network to perform the computation and provide storage services.

The main objective of edge architecture is to provide a better quality-of-experience (QoE) for end users by reducing response time and throughput. It enables different real-time applications and time-critical services to make decisions without any delay. Moreover, owing to the inimitable flexibility of EC systems, edge devices are compatible with almost all hand-held electronic devices such as smart phones, personal digital assistants, laptops and even on-board units. The applications and services are installed in the edge devices, which process data in close proximity to the users to reduce latency problems. Furthermore, instead of transferring all the data to the centralized server, the edge device filters the information, thus mitigating stress in the backhaul links and enhancing bandwidth utilization in the network. Asignificantinnovation made in internet-based computing technology is FC technology which is often interchangeably used with EC.

Both EC and FC architecture push the intelligence closer to the data source, but the key difference is that FC pushes the intelligence up to the local aAreanetwork (LAN) level, whereas EC pushes the intelligence directly to the device or to a dedicated edge server [39]. Like EC, FC also garners huge recognition and is widely utilized in various real-time and IoT applications which demand faster data processing. A fog server installed with the LAN processes the data to attain intermediate results and filters the data before transferring the same to the cloud server. As the EC and FC more or less exhibit the same advantage with regard to computation and storage, the performance difference is based on the applications which use them.

Another significant computing technology which has dominated the tech-driven world for more than a decade is CC technology. In CC architecture, computation and storage capabilities are moved to a distant centralized server called the cloud. All the processing and storage occurs at this single point which is handled by a centralized data center. Primarily, cloud architecture can be divided into two different layers namely, the upper layer and lower layer. The lower layer represents the end-user devices with network connectivity and the upper layer represents the centralized servers inbuilt with huge processing and storage power. Using a client-server protocol, the end-user devices can be connected to the cloud servers using either a wired or wireless network. As all the computational functionalities and storage are undertaken at the centralized server, the front-end devices do not require any computing intelligence or data storage capability. Basically, cloud servers can deliver three different services namely, software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS). Although these services seem to be more reliable, the biggest concern is high latency and heavy bandwidth utilization. When compared with EC, cloud servers suffer from a high processing delay that can affect the overall efficiency of real-time applications. Also, the cloud handles enormous amounts of data at a single server point, which can create congestion in the cloud servers and backhaul links. Similar to CC architecture, MCC architecture is another paradigm which extends CC by distributing the service to multiple clouds. MCC architecture shares the entire work flow model with the CC and makes the verification of data redundancy which has a high recovery rate. When compared with EC, MCC also has the same disadvantages as CC, along with complexity and portability issues.

The analysis of features on edge paradigms with cloud computing, highlights that the availability and scalability properties are high when compared with the cloud. Nonetheless, the network architecture bottleneck is overcome by edge as it is distributed and decentralized. Though the paradigms of edge such as fog-computing, mobile edge computing come from varying backgrounds, they all tend to support virtualization infrastructure (such as cloudlet / fog nodes). One another benefit of edge over cloud is the foreseeable low latency and packet delay or jitter.

Therefore, by conducting a detailed comparative analysis of all the major network-based architectures, EC is shownto be the most sought-after architecture for running real-time applications and IoT intelligent services, as ilustratedin Figure 2. In adition to its high demand in IoT smart solutions, EC architecture is also widely preferred across several conventional business applications.

A. RESEARCH VIEW ON EC

Many academicians and research practitioners have effectively used EC for different applications to enhance the robustness and dynamicity of their systems. As EC promises an impelling reduction in the latency, effective bandwidth utilization and low energy consumption, many real-time applications utilizing CC have upgraded to EC. In this section, we highlight the significance of EC from various researchers' points of view and a study of different applications that use EC. Recent advancements in augmented reality (AR) applications demand real-time processing and a faster response time. Conventional computing techniques such as CC cannot cope with the growing demands of AR processing. In order to address this issue, Ali and Simeone [14] proposed an EC-based scheme for AR applications to achieve efficient data processing and a quicker response time. Their scheme uses an energy-efficient resource allocation scheme to enhance reliability for AR applications [14]. Yet another driving trend revolutionizing living rooms is IoT-based smart home applications. Smart home applications are mission-critical and demand low latency and preservation of locality. An EC-based scheme fulfills these demands of smart home applications.

A design by Vallati *et al.* [34] achieves a dramatic reduction in latency and ensures the security of locality information. Sapienza *et al.* [35] designed an EC-based smart city application that can effectively detect certain critical events, such as terrorist threats, natural calamities, man-made disasters, etc. In [36] and [37], the researchers selected an EC-based architecture to address various network-related issues in vehicular technology. The authors present an efficient scheduling and adaptive offloading scheme that reduces the computation complexities in a VANET environment. Furthermore, EC architectures play a vital role in E-health applications whichcould save the lives of many patients. As EC guarantees a faster response and higher throughput, the decision-making process becomes faster and easier in E-health applications. For instance, Ali and Ghazal [38] proposed a real-time heart attack mobile detection service (RHAMDS) using EC which has lower latency when combined with geographical awareness which can accurately detect a patient's location. Therefore, a brief analysis of the contribution of EC across different domains by numerous researchers certifying EC to be a truly reliable computing system, aims to provide an efficient service in a decentralized manner. Table 1 details the advantages of EC over other computing techniques, providng a comparative analysis of the various computing characteristics.When compared with the characteristic features of different computing techniques, EC has better results than CC and MCC and exhibits an almost similar performance rate with the FC system.

The need for the security on edges were triggered and emphasized by researchers due to the put-ups of potential

TABLE 1. Summary – computing characteristics.

Characteristics	Cloud	Fog	Multi-cloud	Edge
Latency	High	Low	Very High	Low
Bandwidth Utilization	High	Low	Very High	Very Low
Response Time	High	Low	High	Low
Storage	High	Low	Very High	Low
Server Overhead	Very High	Low	High	Very Low
Energy Consumption	High	Low	High	Low
Network Congestion	Very High	Low	High	Low
Scalability	Medium	High	Medium	High
Quality of Service and Quality of Experience	Medium	High	Medium	High

insecure sensors, IoT devices installation in composite environments like smart cities and industrial plants. Therefore, even intelligent edges uncovers data and devices to threats. One such threat to be addressed on an edge paradigm is the technological restriction of the infrastructure. For instance, edge data centers with micro-servers (Raspberry Pi) may lack hardware protection when compared with the other commodity servers. The other possible threat is the combined security deployment over multiple layers of technologies like network to mobile to cloud on a heterogeneous environment. The threats on edge paradigm may shadow the benefits, as proper privacy and security mechanisms are not introduced. Therefore, the need for security on edge is highly recommended by researchers.

B. SERVICE BENEFITS OF EC

As numerous business services have transformed from the cloud to the edge owing to its cutting-edge computing services, the economy of scale has significantly improved, providing tremendous benefits to the business services that provide the infrastructure as well as the enterprises using it. Following are some of the significant service benefits of the edge:

- Using EC, undertaking data analytics is faster which improves the overall performance of real-time applications.
- The data center implementation cost is notably reduced by selecting nodes as edge servers.
- It mitigates stress in the backhaul links by alleviating network traffic.
- It effaces single point of failure and adapts distributed computing.
- It increases virtualization and scalability in the network.
- It improves the QoS by minimizing the data transfer distance.
- It achieves reliability by installing applications in close proximity to the end device.
- It is inbuilt with less complex and easy-to-manage hardware devices.

Thus, regardless of whether it is an individual device, or at the fleet or plant level, EC has become a mainstream technology that increases the efficiency and productivity of the business and industrial sectors.

C. COMPUTING VS STORAGE SERVICE OF EC/FC/THE CLOUD/MCC

In EC, the response time in computation services is in milliseconds and supports various application as a service (AaaS) schemes. EC can effectively perform data analytics, predictive analysis and virtualization on edge servers. Relying on its lower latency, EC enables ubiquitous computing in smart applications, where the user can interact with the system in real time and have a better QoE. EC supports storage services locally and keeps the data in the server only for a transient time. EC uses storage more for caching than storing, so the data that resides in the edge server is stored only for a transient time. As the storage capacity is limited in EC, large business applications handling enormous amounts of data cannot be handled by EC storage services. Computing services in FC share the same advantages of EC. While the computing capabilities are moved to the LAN it also provides some additional services like cooperation as a service (CaaS) and network as a service (NaaS) to the end users. The storage service in FC gives storage space for a short duration. As the fog nodes lie at the edge of the LAN network, there is more storage space than the EC storage service. Based on the FC server storage configuration, data can reside in the server from hours to days.

The computing services in both CC and MCC can be broadly classified as IaaS, PaaS and SaaS. The computation

TABLE 2. Summary – computing services.

	Edge Computing	Fog Computing	Cloud Computing	Multi Computing
Computing Service	Response time in milliseconds	Response time in seconds to minutes based on the application.	Response time in minutes	Response time in minutes
Storage Service	Temporary storage, doesn't support huge data collection	Data can be stored for hours up to days	Permanent storage supports huge data collection	Permanent storage, supports huge data collection and data protection

capabilities are very high due to the presence of centralized data centers. Although CC and MCC provision huge computing power, the distance between the server and the end user makes the enterprise vulnerable to high latency, which is not suitable for real-time processing and IoT applications. The storage service in CC and MCC is enormously huge so it can store data permanently,the only difference being that MCC offers more data safety/protection and a greater error recovery rate by mirroring the data in different servers. A detailed comparative analysis on computing services and storage services for a variety of architecturesis shown in Table 2.

D. COMPUTING IN HETEROGENEOUS DISTRIBUTED NETWORKS

For more than a decade, the major contribution and significance of traditional computing schemes such as CC and MCC over heterogeneous distributed networks such as MANETs, VANETs and IoVshas widely enhanced computational capabilities in tech-driven smart city development. The major advantage of cloud-based services is that they provide enormous computing power and storage capacity to these networks. However, the applications used in these distributed networks are mission-critical and the centralized architecture used in CC stimulates the end devices to transfer the data to the cloud server through backhaul links, thus making the backbone network loaded with heavy traffic congestion. Also, due to the distance between the server and end devices, the applications also encounter severe time delay which might affect the overall performance of the system. Therefore, to cope with the ballooning computational demands of smart applications, new computing paradigms such as edge and fog computing have evolved, potentially addressing major challenges and concerns in terms of a low latency requirement, less network utilization, lower implementation cost, etc. These computing services push computing capabilities to the edge of the network and provide computation offloading at close proximity to user nodes, the details of which are shown in Table 3.

Some of the major MANET applications such as interactive media, video streaming, computer games, e-commerce, etc., transmit enormous amounts of data to the cloud. This data transfer increases the overall throughput, hence using EC can significantly reduce data transfer by filtering and processing the data at the edge server. Thus, using EC in MANET applications ensures energy efficiency and less bandwidth utilization for the network. As VANETs and IoVs deal with lifesaving events, the applications become time critical. Using EC to meet this requirement helps process the information in milliseconds resulting in prompt action. As a result, numerous accidents and congestion in the transportation network are avoided. Thus summarizing, EC provides the utmost reliability and scalability, garnering huge demand and be a strong preference for various smart city projects across the globe such as smart homes, smart sensing, smart transportation, smart healthcare, smart security and much more.

E. PRIVACY AND SECURITY ISSUES RELATING TO EC

EC plays a pivotal role in delivering a latency sensitive service to various heterogeneous network smart applications, however, it could impose issues related to the security and privacy of the system. Some of the major challenges are briefly summarizedas follws:

When compared with CC, EC servers are distributed at the edge of the network which makes the system more vulnerable to various security threats. Existing encryption standards will not be applicable in EC due to the resource constraints existing in the servers. In order to provide reliable protection against security threats and attacks, a light-weight authentication scheme needs to be modeled where the EC servers authenticate the end devices without any time delay. Another issue for EC is the challenge in managing trust between the edge server and end nodes. As edge servers are distributed throughout the network, the trust computation from one EC server cannot carry forward the trust to the other EC servers. As node mobility is high in distributed networks such as VANETs and MANETs, the nodes will encounter different edge servers and thus, need to be authenticated from time to time. To do this, a reliable trust management system needs to be integrated into the EC environment which is capable of handling trust from both the servers and end nodes.

TABLE 3. Computing in MANET and VANET.

	VANETs	**Cloud**	**Edge**	**MANETs**	**Cloud**	**Edge**
Application	Road safety	Available	Available	Smart home	Possible	Available
	Parking	Available	Available	Smart city	Possible	Available
	Traffic Signals	Available	Available	Smart grid	Possible	Available
Services	Network as a service (NaaS)	Yes	Yes	Software as a service (SaaS)	Yes	Possible
	Storage as a service (STaaS)	Yes	Possible	Platform as a service (PaaS)	Yes	Possible
	Cooperation as a service (CaaS)	Yes	Yes	Infrastructure-as-a-service (IaaS)	Yes	Possible
	Computing as a service (COaaS)	Yes	Yes	Mobile backend as a service (MBaaS)	Yes	Possible
Infrastructure	Static	Highly applicable	Highly applicable	Centralized	Highly applicable	N/A
	Dynamic	Highly applicable	Highly applicable	Decentralized	N/A	Highly applicable
	Stationary	Highly applicable	Highly applicable	Hybrid	Highly applicable	Highly applicable
Security Challenges	Authentication	High Challenge	High Challenge	Data Protection	Less Challenge	High Challenge
	Vehicular Comm	High Challenge	Less Challenge	Access control	High Challenge	Less Challenge
	Localization	Less Challenge	High Challenge	Availability	High Challenge	Less Challenge

In addition to this, maintaining the privacy of data is equally challenging in EC, as information processing is pushed to the edge of the network. Consequently, smart applications will generate a greater amount of personalized information and location awareness data that can easily be compromised due to the openness in the environment. Thus, a reliable data protection and trust validation scheme needs to be incorporated in the system which can significantly protect the geographical location accuracy and personal data of the users.

IV. INTEGRATION OF IoT WITH EDGES

Currently, more than 20 billion IoT devices are deployed on the Internet, and this number is expected to increase in scale over the next five to 10 years [39], [40]. The IoT comprises billions of Internet-connected devices or things, each of which can sense, communicate, compute, and potentially actuate, and can have intelligence, multimodal interfaces, physical/virtual identities, and attributes [39]. Edge datacenters are mainly deployed to bring the computing facilities from the IoT infrastructure. Current IoT devices generatea huge amount of data termed as big data [41], hence we need a dedicated computing infrastructure to process this in near real-time.

In recent days, IoT devices are being deployed to sense and/or work as the source of data and transmit these data to the cloud for processing and storage. Due to the high demand for real-time data analysis, edge computing comes into the picture. In current research, edge devices are deployed in the base station of the network, so that data streams transmit to cloud through the edge devices. Hence, edge devices can perform lightweight computing in the emerging situation and transmit the data streams to the cloud for batch processing. The combination of the IoT, edges and the cloud is also known as fog computing.

V. RELATED WORK

Ali and Simeone [14] proposed a novel energy-efficient resource allocation scheme for augmented reality applications using mobile edge computing (MEC). In this scheme, the system overhead is effectively reduced by the joint optimization of communication and computational resources. A successive convex approximation function is utilized to ensure optimized energy consumption in MEC. The results show that the proposed system achieves better offloading when compared with conventional techniques [14]. Amjad *et al.* [15] presented a resource allocation framework for IoT applications based on EC. The framework integrates a dynamic resource allocation scheme with the EC resource requirement scheme to provide an efficient solution for the enterprise cloud. As the cloud operating system supports bidirectional resource sharing, a universal resource allocation framework for IoTis achieved. The experimental results show that the proposed system achieves more efficiency in handling the resource allocation requests [15]. Beraldi *et al.* [16] developed a cooperative load balancing scheme called CooLoadwhich is installed at the edge of the network to reduce execution delay. Based on this cooperative scheme, the data centers share their buffer space with one another based on its availability. If a data center buffer is full, the received request is forwarded to another data center with buffer space availability. The experimental results show that the proposed system significantly improves the performance of the computing services [16].

Badarneh *et al.* [17] designed a wireless-based software-defined mobile edge computing (SDMEC) framework to enhance the management of storage services in wireless networks. Based on the increase in network demand, the proposed system auto-scales the network storage resources to deliver a better QoE. The experimental results show that the proposed system achieves minimum latency in the network [17]. Chen *et al.* [18] presented a game theoretic approach to study the offloading problem for mobile-edge cloud computing. In order to achieve an optimized computation in the network, the system formulates a multi-user computation offloading game among the mobile device users in a distributed manner. The game approach effectively offloads computation among multi-users and successfully achieves the Nash equilibrium property. The experimental results show that the proposed system achieves better offloading performance [18]. Dama *et al.* [19] provided a solution for connectivity problems in the cellular Internet of Things (C-IoT) with EC. In this scheme, the system adopts two different RACH mechanisms which reduces the number of collisions in the network. Using the RACH mechanism, numerous devices can be integrated into C-IoT with less energy consumption. The results show that the proposed mechanism allows C-IoT devices to connect without any connectivity issues [19]. Kumar *et al.* [20] designed a smart grid data management scheme for a vehicular delay-tolerant network in the mobile edge computing paradigm. A virtual machine migration approach is utilized to minimize the energy consumption at the data centers. Both computing and communications issues are managed by electric vehicles located at the edge of the network and autonomous decisions are made. The experimental results show that the proposed system achieves higher throughput and minimum delay in the network [20].

Laredo *et al.* [21] proposed a self-organized critical approach to achieve energy efficiency in load-balancing computational workloads. The system follows a Bak-Tang-Wiesenfeld sand-pile cellular automation model for scheduling independent tasks in the system. The experimental results show that the proposed system achieves better resource utilization without compromising the QoS [21]. Le *et al.* [22] proposed a novel edge computing system architecture for highly dynamic and volatile environments to deliver fail-proof applications. The proposed system automatically detects the partial failure of edge networks and dynamically changes the device clusters to peer-to-peer communications until the edge network recovers. The experimental results show that the proposed system is resilient and efficient with mobile edge computations over unreliable networks [22]. Liyanage *et al.* [23] designed a mobile-embedded platform as a service (mePaaS) model for the edge IoT devices. A resource-aware autonomous service configuration is performed at the edge of IoT networks to manage hardware resource availability. The test-bed results show significant improvement in the computation performance of the mePaaS nodes [23]. Li *et al.* [24] developed a novel MEC architecture, achieving minimal latency in cellular-based vehicular networks. The system implements an MEC server which connects with the road side base-stations to provide a flexible vehicle-related service. Further, to promote network customization in vehicular networks, the proposed system incorporates MEC-assisted network slicing and an optimized traffic scheduling policy. Finally, the performance of mobility management is enhanced by redesigning the inter-cell handover mechanism for the vehicles [24].

Liu *et al.* [25] proposed a Markov decision process for the task scheduling policy in MEC systems. This finds the point of delay in the optimal task scheduling policy in the system, and the proposed model uses a one-dimensional search algorithm which minimizes the average delay and power consumption in the mobile edge device. The experimental results show that the proposed system achieves minimum delay when compared with the baseline approaches [25]. Mao *et al.* [26] developed an effective computation offloading strategy for MEC systems using energy harvesting (EH) mobile devices. The proposed model adapts the Lyapunovoptimization-based dynamic computation offloading (LODCO) algorithm to address offloading decisions. The decisions are made based on the current system state without requiring distribution information of the EH processes. The simulation results show that the proposed system outperforms the benchmarked policies [26]. Mao *et al.* [27] presented a low-complexity sub-optimal algorithm for MEC systems. The system uses a flow-shop scheduling theory to determine optimal task offloading and the scheduling decisions are performed by the convex optimization techniques. The simulation results show that task offloading scheduling ensures less delay than conventional techniques [27].

Rimal *et al.* [28] introduced the novel concept of using fiber-wireless (FiWi) access networks to optimize MEC services. A two-layer time-division multiplexing (TDM) based unified resource management scheme is proposed for MEC over ethernet-based FiWi networks. An investigation is made on the design scenarios of the MEC over FiWi networks using different radio access network (RAN) technologies. The analysis proves that the proposed scheme provides reliable energy consumption with MEC over FiWi [28]. An extension of the work [28] is presented by Rimal *et al.* [29]. The authors proposed a MEC enabled FiWi broadband for low-latency and resource-intensive MEC applications. Further, to build

TABLE 4. Edge, Fog, Cloud Standards.

Edge	Fog	Cloud
Dedicated application host at the edge server	Real-time control at the LAN point	Resource pooling at data center
Embedded OS at the edge server	Reliable data communication	Efficient scalability access
Device management at the edge of the network	Faster data analytics	Centralized big data analytics

FiWi access, the proposed system integrates the ethernet-passive optical networks (EPON), wireless local area networks (WLANs) and cloudlets. Additionally, to offload delay in the network, a novel cloudlet-aware resource management scheme is proposed by the FiWi dynamic bandwidth allocation process integrated with a time division multiple access. The experiments are carried out in the test-bed and the proposed analytical model is effective in reducing delays and conserving more energy [29]. Rodrigues *et al.* [30] proposed an analytic model for minimizing service delay in the ECC systems. System service delays, such as processing delay and transmission delay in the network are minimized by using two cloudlet servers. By improving the virtual machine migration, the computation and communication overheads are reduced in the network. The experimental results show that the proposed method has lesser processing delays when compared with other conventional methods [30]. Despite of all the other reasons for the migration to edge is the need for a minimum latency over the network and a predictable packet delay variation. The analysis over the features of both edge and cloud is clarified in detail with Table 1.

VI. FUTURE DEVELOPMENTS ON EC

Today, the IoT is almost everywhere and is being incorporated in many different ways. It is predictedto be the major driving factor for the future. In upcoming years, innumerable sensors, computing systems and Internet-equipped smart applications will soon take the entire tech world by storm. In order to cope with these mammoth demands, a reliable EC scheme should be executed that can dexterously handle both processing and communication, making it an optimized system. We have discussed a few significant processing models that need to be in-built in future edge-based servers. First and foremost, an efficient computation offloading model should be incorporated to achieve optimized performance in real-time scenarios. This improvised scheme should be capable of allocating appropriate tasks for both EC and CC systems. The second additional feature should be an upgraded resource allocation model integrated to manage the shift between the edge and cloud computing. The final feature that needs to be incorporated is an effective scheduling algorithm that can significantly achieve energy efficiency and at the same time, reliably manage and control distributed EC-based servers in different heterogeneous networks. As an inference of this study on edge paradigms, the integration of edge is still in its embryonic stage; consequently, there are manifold issues that have to be addressedin near future.

VII. CONCLUSIONS

With the staunch objective towards providing a better service to the IoT paradigm, different computing technologies have introduced new standards and policies for numerous IoT applications. Conventionally, CC is one of the most pursued computing techniques, delivering computing resources and other services to IoT applications through the Internet. So, to provide an efficient and upgraded service to IoT smart applications, FC and EC have recently evolved which effectively function by pushing cloud capabilities to the edge of the network. EC and FC technology can provide elastic resources that allow for distributed data processing and protects the data from the drawbacks of traditional centralized architecture.

To conclude, the current standards of EC and FC provide a reliable and an improved quality of service to IoT applications when compared with CC standards. A detailed comparison of edge, fog and cloud standards is given in Table 4. However, to provide an upgraded and efficient service, based on the rising demands of IoT applications, an appropriate computing technology needs to be incorporated. Due to the high implementation cost, the selection of computing technology should be well planned and needs to be tested before implementing and executing real-time applications in the future.

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